

[54] FLUX FOCUSING EDDY CURRENT PROBE

- [75]

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- [21]

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- [51]

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- [52]

U.S. Cl. 324/209; 324/225; 324/240; 324/241; 324/262
- [58]

Field of Search 324/209, 225, 324/226, 229, 239-243, 262

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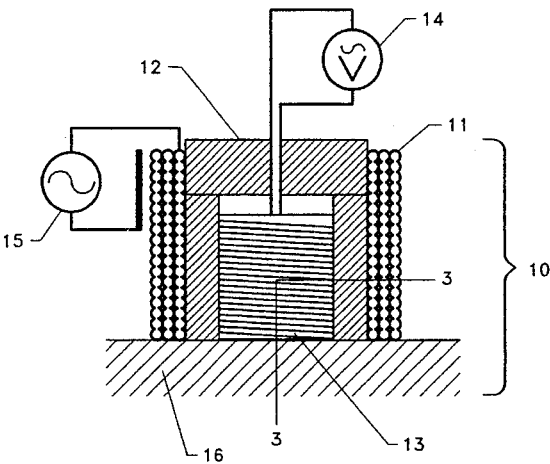
Primary Examiner—Gerard R. Strecker
Attorney, Agent, or Firm—Robin W. Edwards

[57] ABSTRACT

A flux-focusing electromagnetic sensor which uses a ferro-magnetic flux-focusing lens simplifies inspections and increases detectability of fatigue cracks and material loss in high conductivity material. The unique feature of the device is the ferrous shield isolating a high-turn pick-up coil from an excitation coil. The use of the magnetic shield is shown to produce a null voltage output across the receiving coil in the presence of an unflawed sample. A redistribution of the current flow in the sample caused by the presence of flaws, however, eliminates the shielding condition and a large output voltage is produced, yielding a clear unambiguous flaw signal.

The maximum sensor output is obtained when positioned symmetrically above the crack. Hence, by obtaining the position of the maximum sensor output, it is possible to track the fault and locate the area surrounding its tip. The accuracy of tip location is enhanced by two unique features of the sensor; a very high signal-to-noise ratio of the probe's output which results in an extremely smooth signal peak across the fault, and a rapidly decaying sensor output outside a small area surrounding the crack tip which enables the region for searching to be clearly defined. Under low frequency operation, material thinning due to corrosion damage causes an incomplete shielding of the pick-up coil. The low frequency output voltage of the probe is therefore a direct indicator of the thickness of the test sample.

17 Claims, 9 Drawing Sheets



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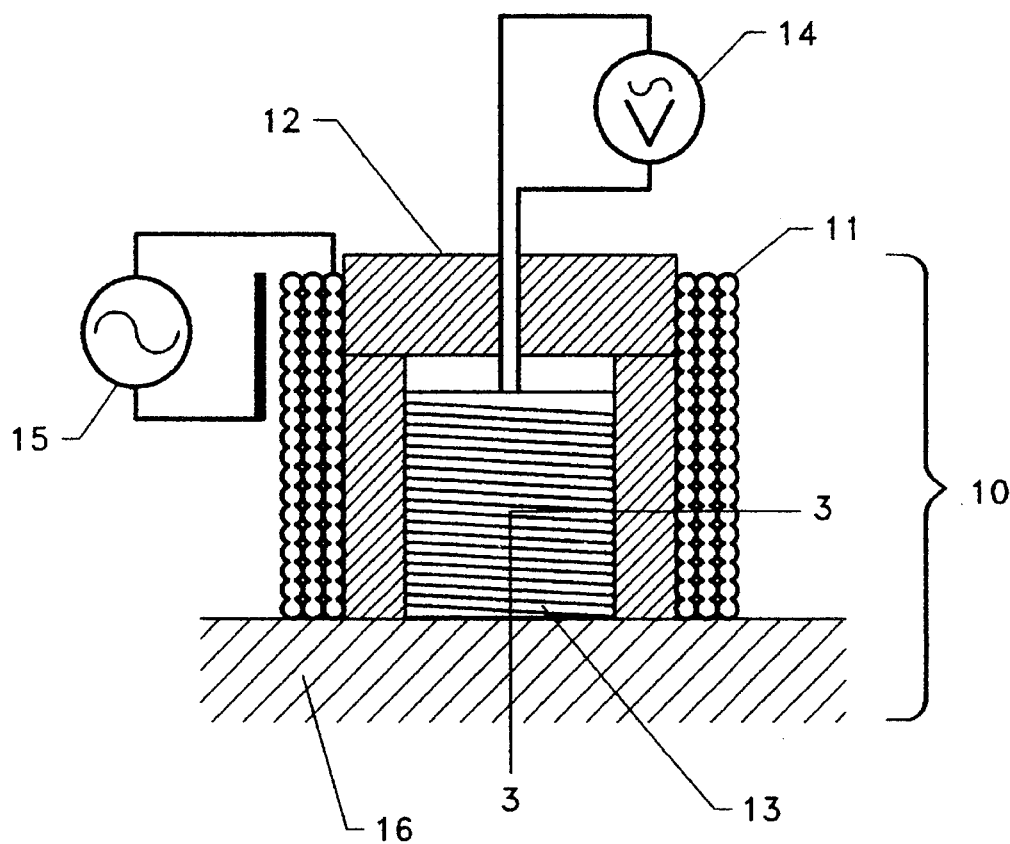


FIG. 1

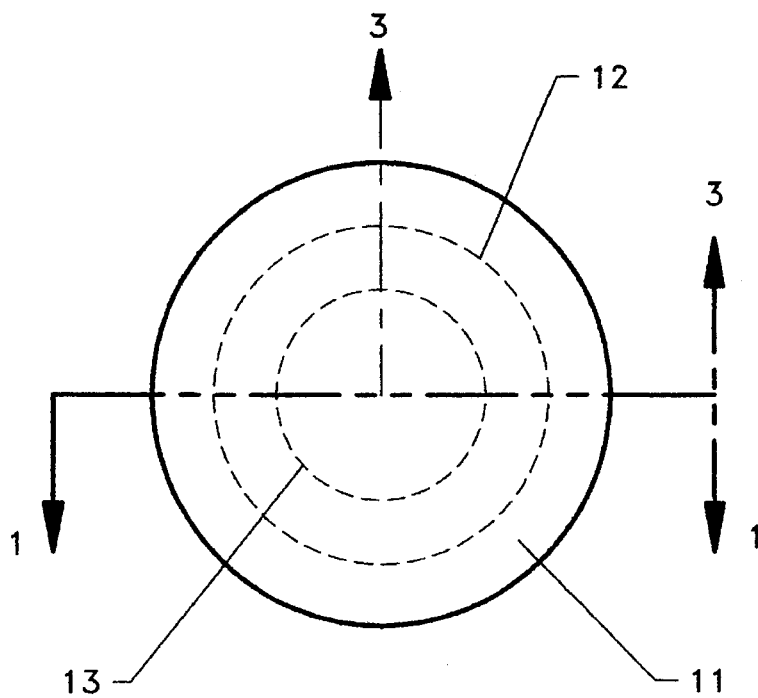
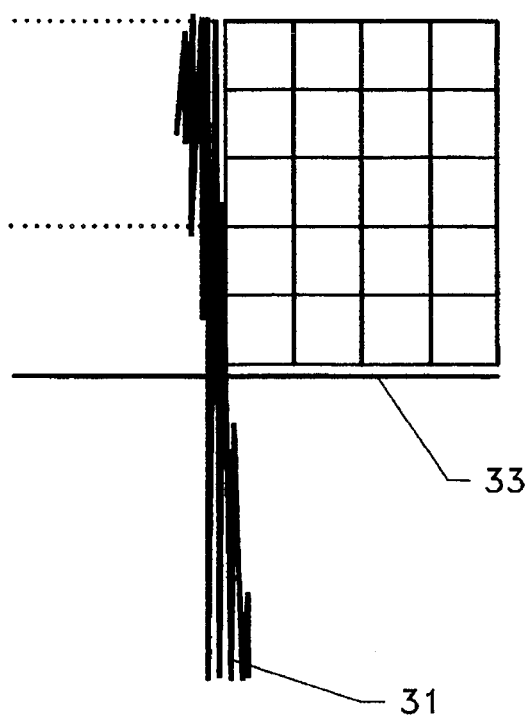
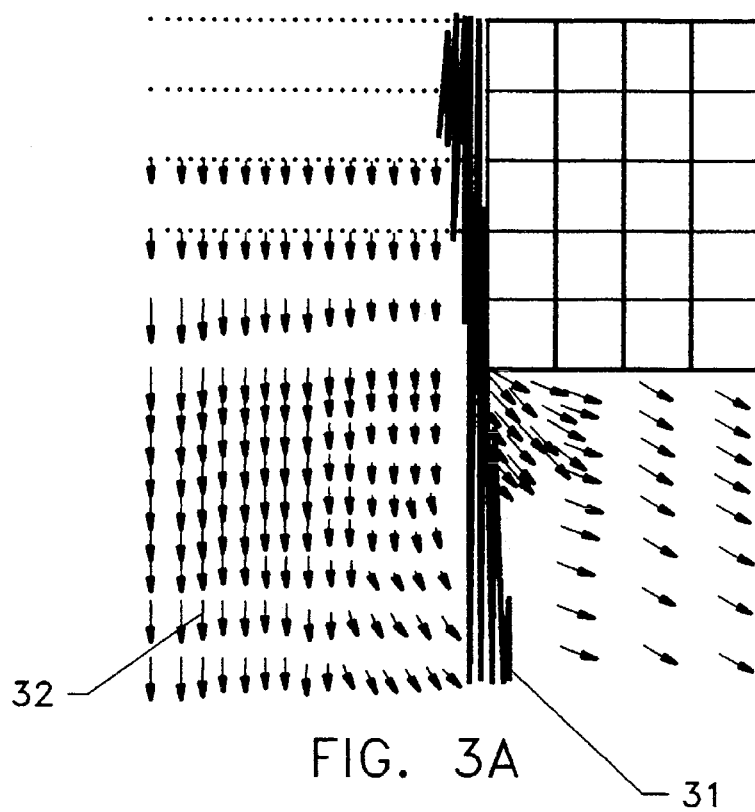
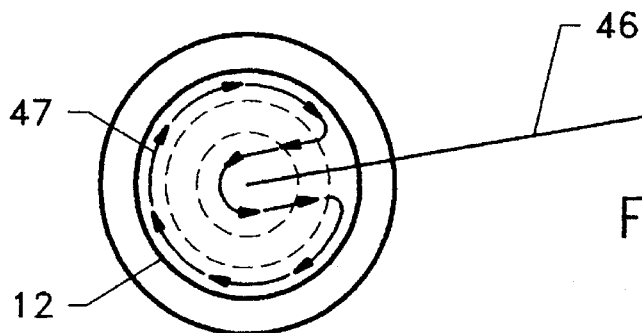
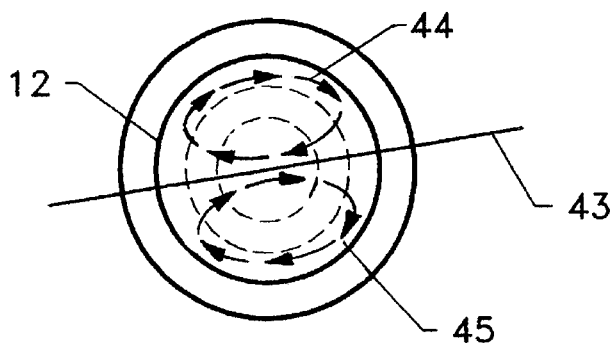
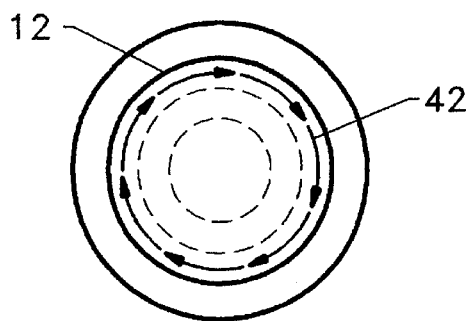
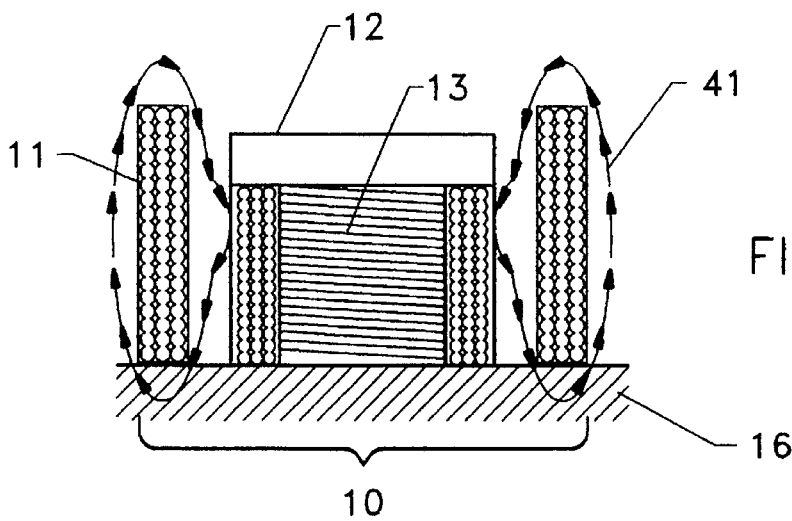


FIG. 2





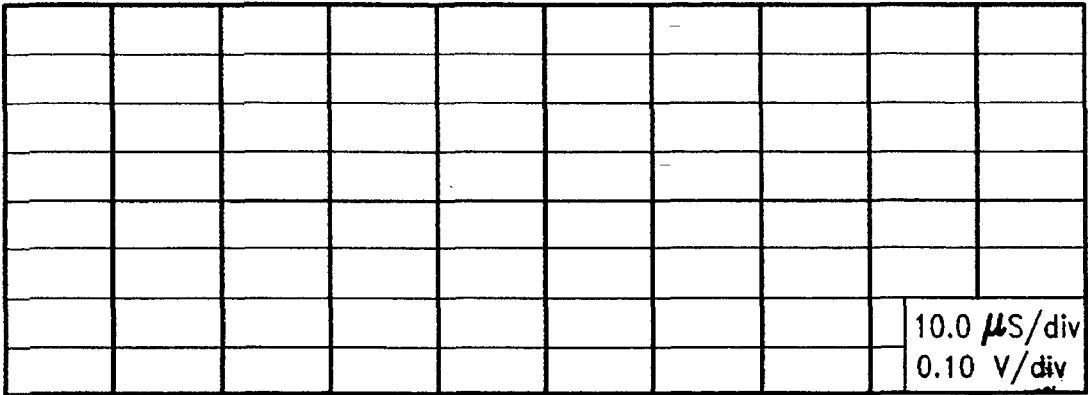


FIG. 5A

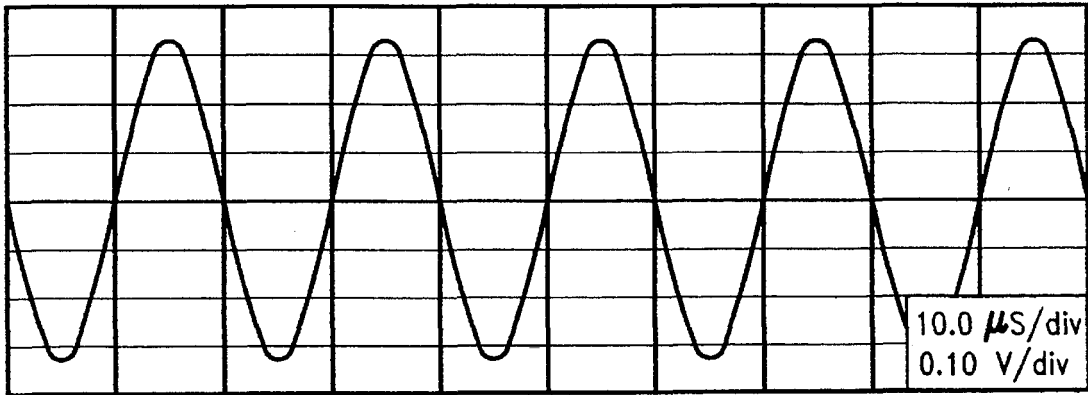


FIG. 5B

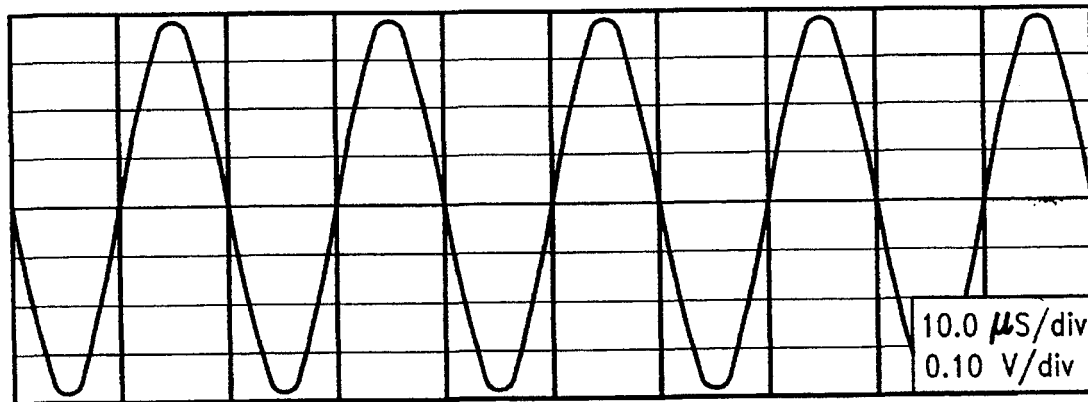


FIG. 5C

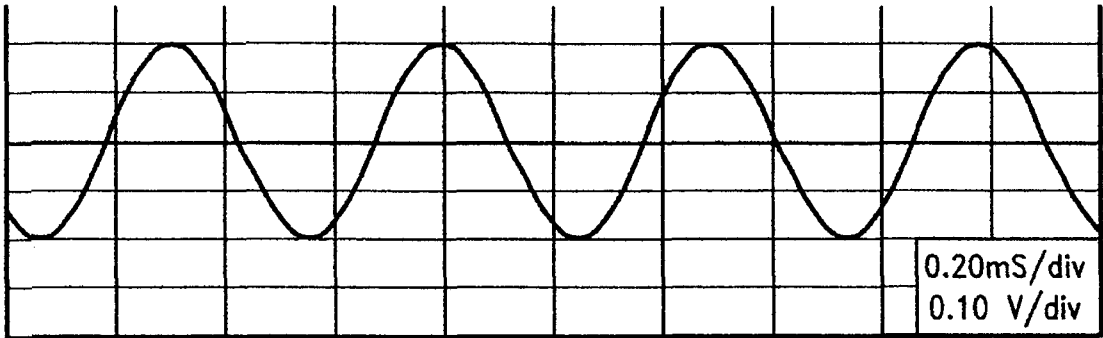


FIG. 6A

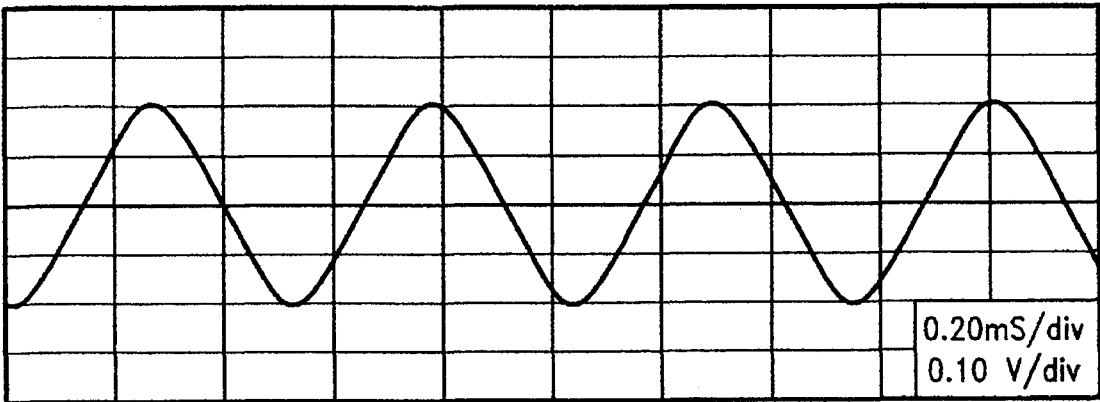


FIG. 6B

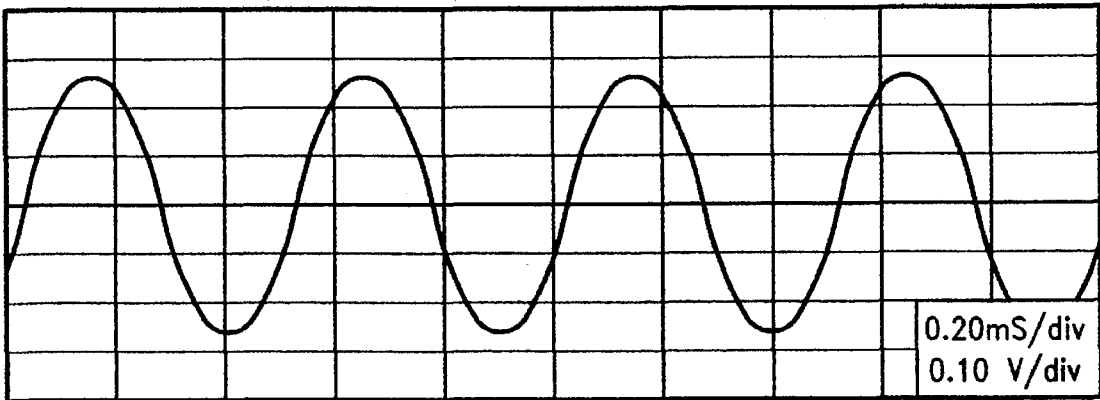


FIG. 6C

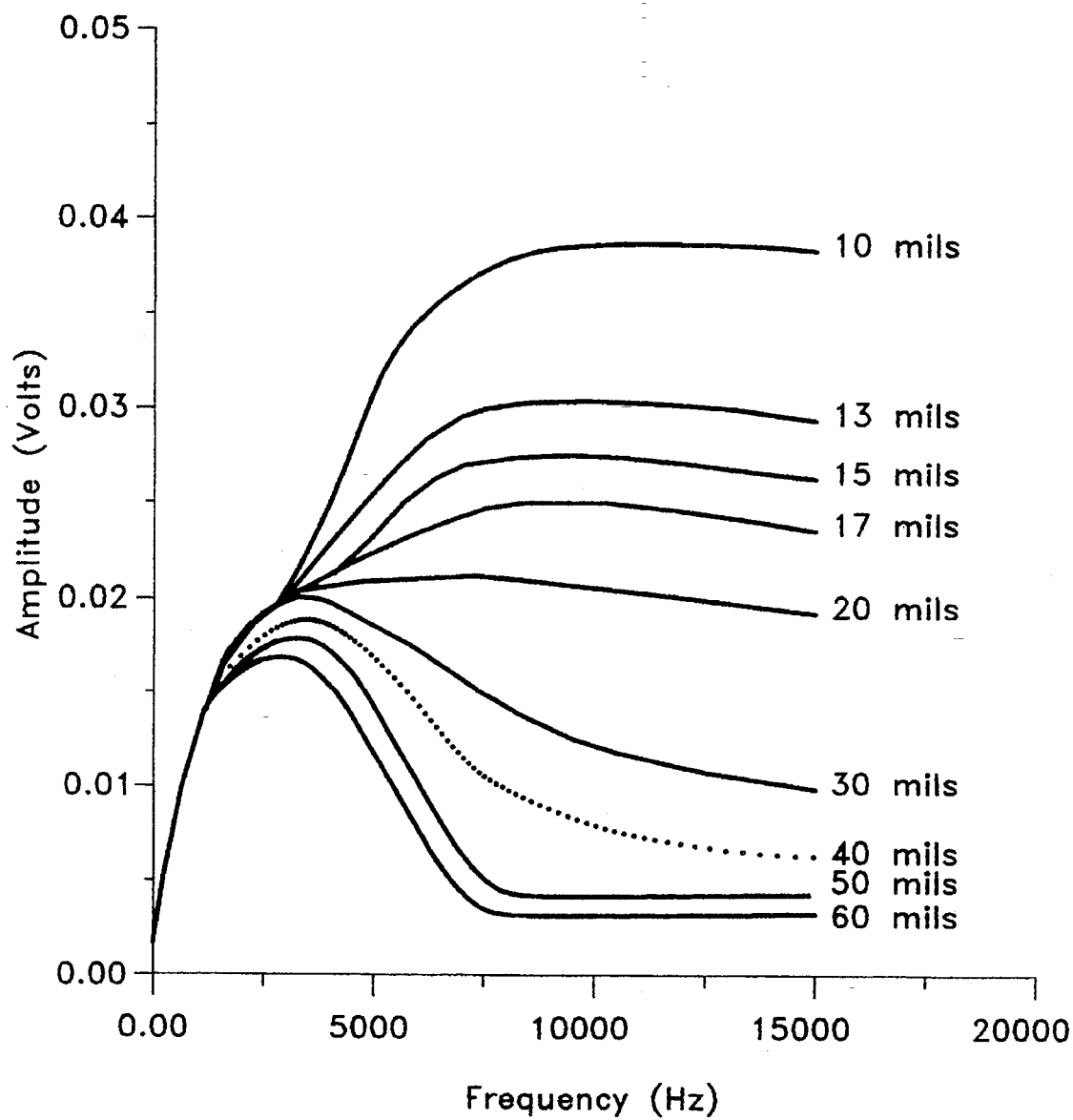


FIG. 6D

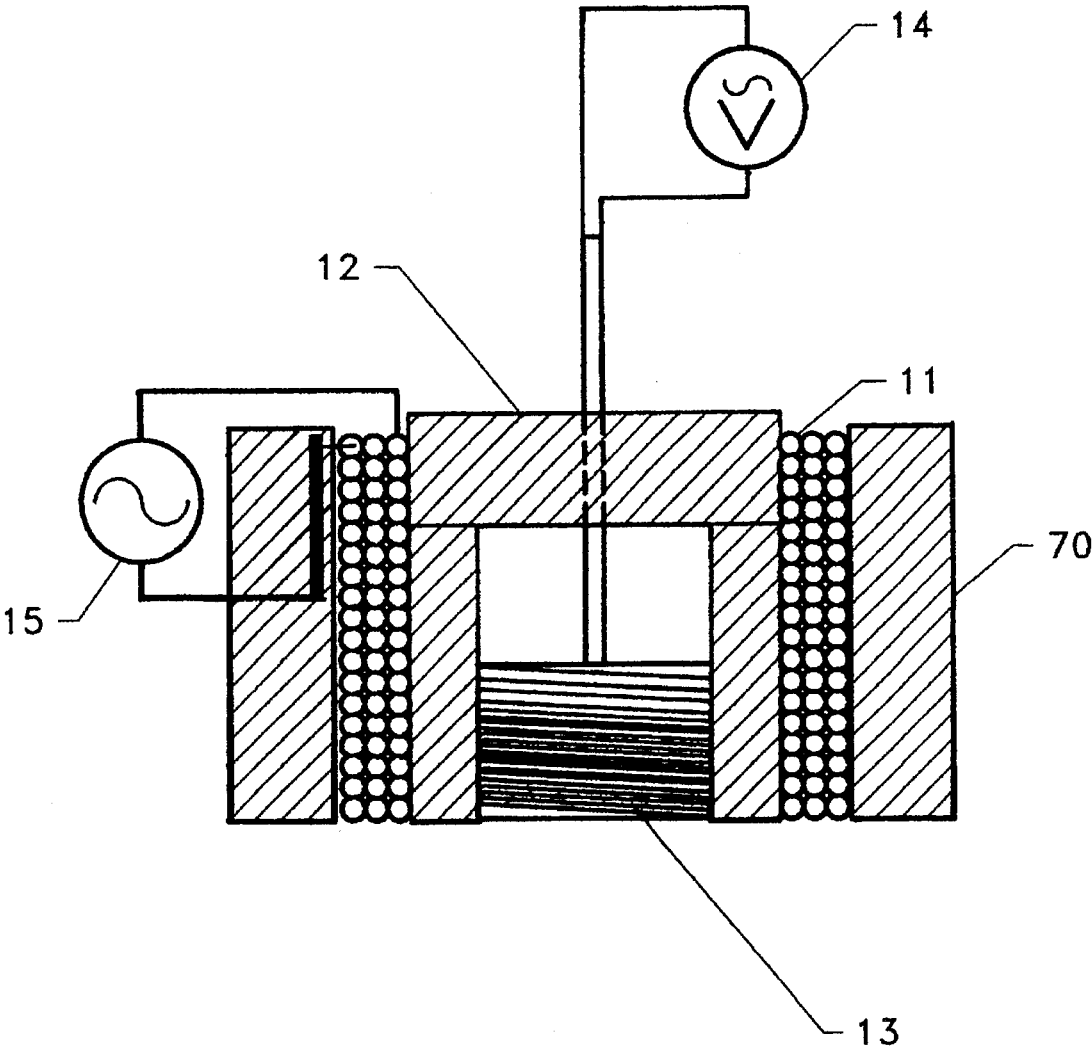


FIG. 7

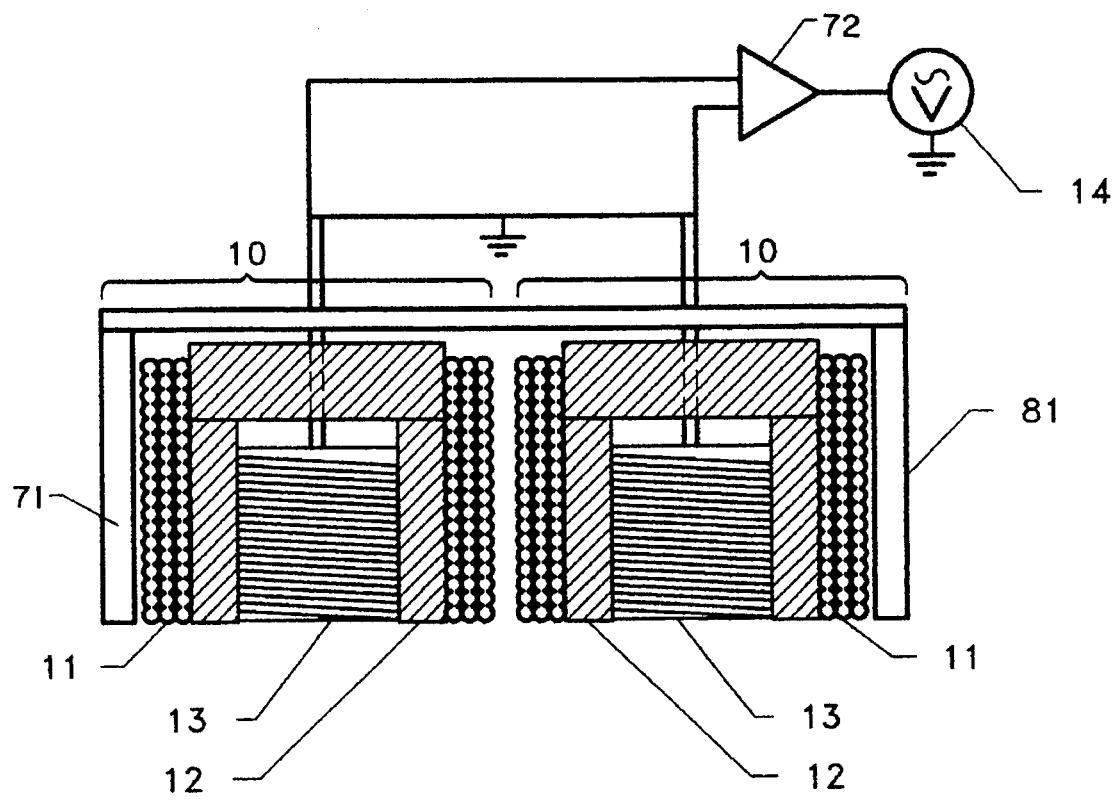


FIG. 8A

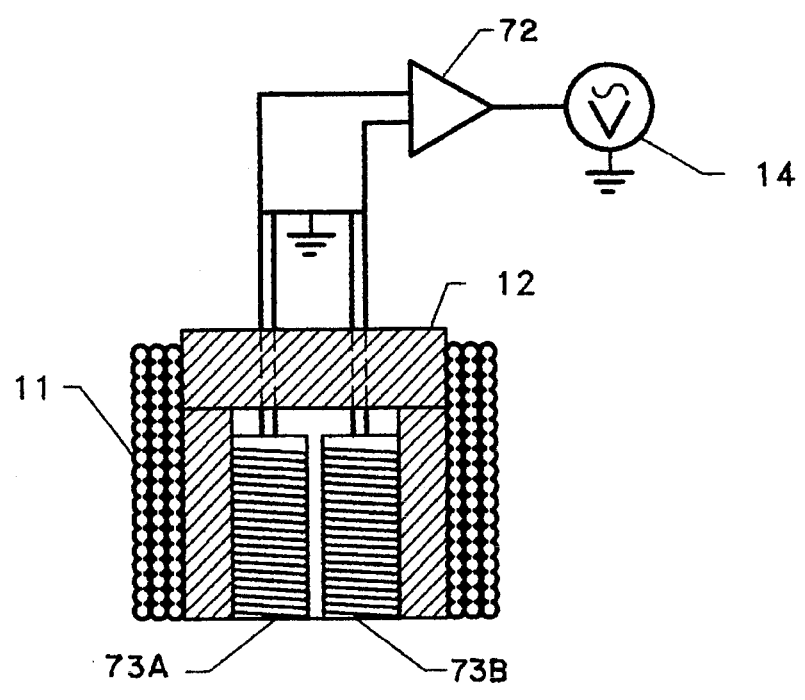


FIG. 8B

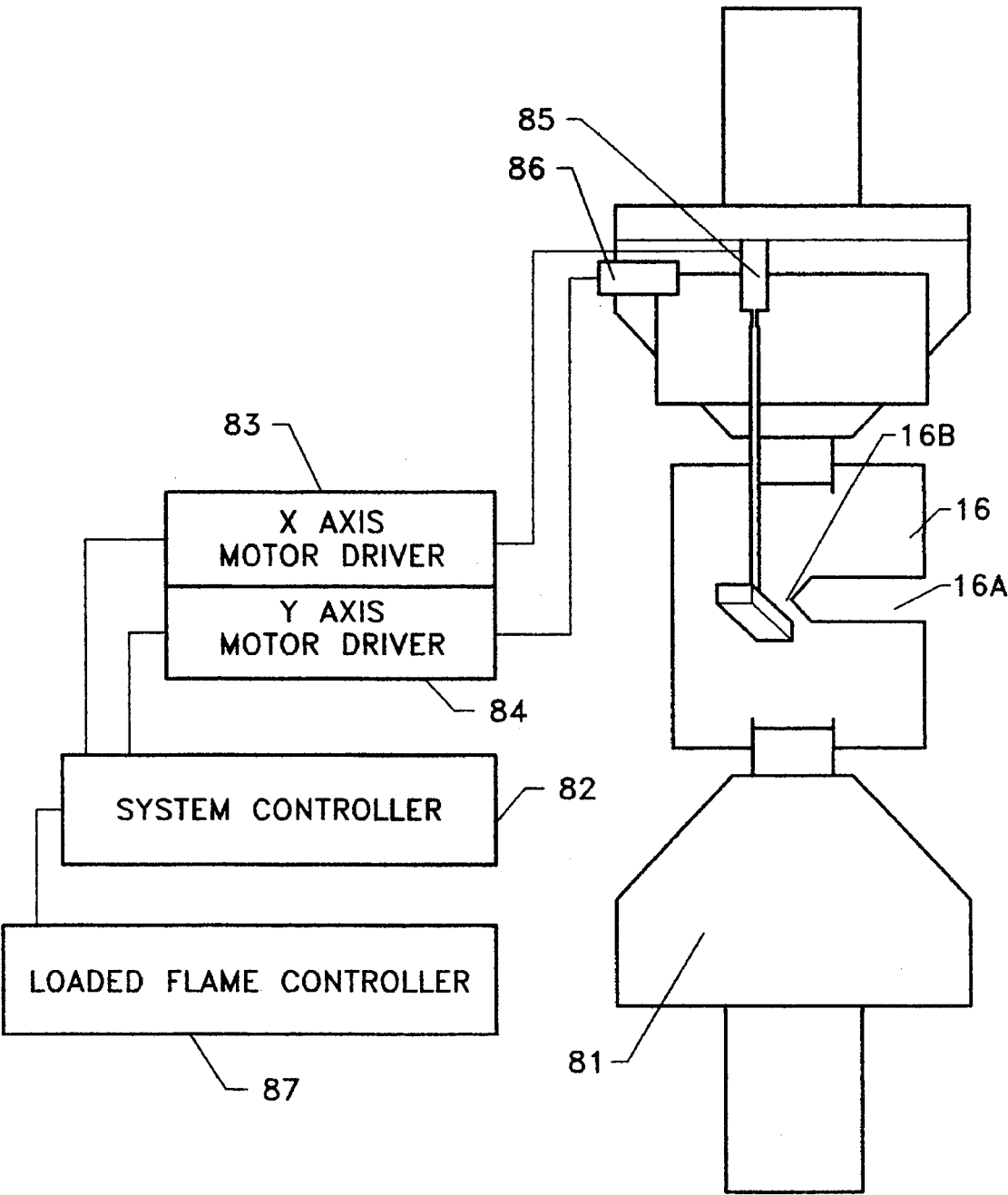


FIG. 9

FLUX FOCUSING EDDY CURRENT PROBE

ORIGIN OF THE INVENTION

The invention described herein was jointly made by employees of the United States Government and contract employees during the performance of work under NASA contracts and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, as amended, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457) and 35 USC 202 in which the contractor elected not to retain title.

This is a continuation of application Ser. No. 08/134,444 filed on Oct. 12, 1993, now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates generally to a device and method for detecting material flaws using the eddy current principle, and more particularly to a flux focusing eddy current probe having separate excitation and pick-up coils, magnetically isolated from one another by a highly permeable flux focusing lens, for detecting different types of flaws or discontinuities at various depths within an electrically conductive material, and an automated method of monitoring crack growth rate and trajectory during fatigue testing. The automated method is not limitative and the invention can also be used for manual testing and fault isolation. The eddy current probe of this invention is simple in construction and operation while providing unambiguous signals of fault indication simplifying support equipment requirements, supporting self nulling capability in no fault conditions during surface fault detection negating the need for calibration standards, maintaining highly resistant lift-off characteristics, and providing highest signal levels at fault tips.

The use of eddy currents to inspect electrically conductive material for flaws is known in the art. Such methods are particularly useful in the nondestructive evaluation of conducting material for surface or internal faults and material thinning. An eddy current probe generally consists of a coil electrically connected to a current generator producing an alternating current within the coil. This generates a time-varying primary magnetic field which in turn induces current flow (eddy currents) in an electrically conductive material positioned in the vicinity of the coil. As described by Lenz's Law, the eddy currents, during their return path, create an opposing secondary magnetic field superimposed on the coil's primary magnetic field decreasing the coil's flux and modifying the coil's voltage effecting the impedance of the coil.

The eddy current's power and direction are dependent upon the specific impedance of the conductive material. In unflawed conditions, eddy current flow is generally parallel to the magnetizing coil's windings. Flaws, such as cracks, pits, and material thinning, in the conductive material create regions of higher resistances at the flaw location which affect eddy current flow. The direction change in eddy current flow reduces the opposing secondary magnetic field and consequently the voltage in the coil. An impedance detecting circuit, which may take the form of an inductive bridge, monitors coil voltage which, if different from an established no-fault condition, indicates a conductive material flaw. Sharp changes in impedance over a localized area would indicate the existence of cracks or other relatively small area flaws, whereas gradual changes in impedance over a broad region of the conductive material might indicate large-area flaws such as a grain change in the metal, an area of material

creep, or material thinning. Though traditional eddy current probes use the same coil for magnetizing the conductive material and for detecting impedance variations caused by changes to eddy current flow, use of separate magnetizing and pick-up coils is known in the prior art. The same principle, however, of monitoring for variations in coil impedance as indicative of a conductive material flaw is applied. This conventional eddy current flaw detection technique often involves complex impedance planes necessitating special test electronics to achieve null balancing and known standards to calibrate probe responses to each type of flaw.

Multiple coils within a single probe can be used as separate magnetizing and sensing means, or they may be used in a more traditional fashion and independently operate the coils as bi-function magnetizing-sensing coils. In the case of a multiple coil probe, the coils can be juxtaposed in a matrix to provide a large detection area, or concentrically arranged to simultaneously detect flaws at various depths. Each coil of multiple coil probes is energized and monitored for impedance variations independently. Multiple coil probes use a shielding material high in magnetic permeability to provide a low reluctance path and divert potentially interfering magnetic fields to separate the coils from one another. The shielding is designed to isolate all interfering signals so that each coil's impedance can be independently balanced. This design provides an ability to perform material testing at several frequencies simultaneously. The conventional eddy current flaw detection techniques are employed which require special test equipment to analyze probe signals.

As the conventional eddy current probe separates from the test material, the eddy currents induced within the material rapidly decrease resulting in a similarly decreasing opposing magnetic field which directly affects the resistance and inductance of the probe's coil. Abrupt changes occur to the impedance balance being monitored for fault indications making traditional eddy current probes unusable during these lift-off conditions.

In addition to detecting existing flaws in conductive material, determination of fatigue crack growth criteria in structural materials is important to predict material fatigue failure limits. Current approaches to testing fatigue cracking include optical methods and other length measuring techniques such as crack mouth opening displacement gauge and four point potential drop method. Each of these procedures requires long periods of continuous monitoring by well trained operators to record fatigue crack tip locations and to adjust experimental controls in compliance with experimental designs. Though the crack mouth opening displacement gauge and four point potential drop method could potentially be automated to reduce operator time requirements, only overall crack length data can be provided and the fatiguing process must usually be stopped to make the crack length measurements.

Eddy current devices have also been used to monitor fatigue crack growth during fatigue. This approach to monitoring fatigue crack growth has been automated, though, again, only overall crack length data can be provided. The traditional eddy current probe which implements impedance measurement techniques to identify the presence of test material faults is not conducive to tracking the crack tip which supports crack trajectory as well as crack growth rate.

OBJECTS

Therefore, it is an object of the present invention to overcome or mitigate these problems and to provide a

flux-focusing eddy current probe whose fault detection characteristics provide unambiguous fault detection signals enhancing the confidence level of fault detection and reducing the need for special test electronics. Through the use of the present invention, a flux-focusing characteristic of probe signals during surface fault detection eliminates the need for known standards of specific types of flaws. Further, a single probe design and instrument configuration performs surface and subsurface eddy current fault detection.

It is a further object of the invention to establish a method which supports automated monitoring of faults in conducting material. The use of this method will perform continuous tracking and archiving of fatigue crack growth rates and trajectory during the fatigue process as well as automatically controlling conducting material loading conditions based on measured fatigue data and experimental designs.

SUMMARY OF THE INVENTION

The present invention is directed to a flux-focusing eddy current probe that satisfies the need for unambiguous signals of fault detection, reducing the need for special test equipment. The flux-focusing eddy current probe performs non-destructive evaluation of electrically conductive material. The probe uses an excitation coil to induce eddy currents in conducting material perpendicularly oriented to the coil's longitudinal axis. A separate pick-up coil, surrounded by the excitation coil, is used to detect generated fields. Between the excitation coil and pick-up coil is a flux focusing lens which magnetically separates the two coils and produces high flux density at the outer edge of the pick-up coil.

The present invention is further directed to an automated eddy current system that satisfies the need to perform continuous fatigue testing. This system performs fatigue evaluation of conducting material and is dependent upon the use and characteristics of the flux-focusing eddy current probe. A computer interprets the signal from the probe to control the probe's position over the conducting material and to control the loading of the conducting material under test. A method for performing the automated testing requires a load to be applied to the conducting material to produce a fault. The flux-focusing eddy current probe scans the conducting material and signals the computer once a fault is detected. The computer then adjusts the loading on the material and position of the probe to continue the test to completion.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

FIG. 1 shows a cross sectional view across line 1—1 of FIG. 2 for an elevation view of a flux-focusing eddy current probe constructed in accordance with the principles of this invention;

FIG. 2 shows a plan view of the flux-focusing eddy current probe illustrated in FIG. 1 with the receiving coil shown in phantom;

FIG. 3A shows a cross sectional view across line 3—3 of FIGS. 1 and 2 of the magnetic flux lines when the flux-focusing eddy current probe is energized in free space;

FIG. 3B shows a cross sectional view across line 3—3 of FIGS. 1 and 2 of the magnetic flux lines when the flux-focusing eddy current probe is energized and in contact with an unflawed electrically conductive material;

FIG. 4A shows an elevation view for the magnetic field of the excitation coil which generates eddy currents in conductive material as focused by the ferromagnetic lens;

FIG. 4B shows a plan view of the eddy current flow in unflawed electrically conductive material;

FIG. 4C shows a plan view of the eddy current flow in flawed electrically conductive material where the flaw divides the probe's circumference;

FIG. 4D shows a plan view of the eddy current flow in flawed electrically conductive material where the flaw tip lies within the probe's circumference;

FIG. 5A shows a flux-focusing eddy current probe's signal level response for a 50 KHz, 10.0 V p-p excitation coil signal when the probe is in contact with an unflawed aluminum alloy plate;

FIG. 5B shows a flux-focusing eddy current probe's signal level response for a 50 KHz, 10.0 V p-p excitation coil signal when the probe is in free space;

FIG. 5C shows a flux-focusing eddy current probe's signal level response for a 50 KHz, 10.0 V p-p excitation coil signal when the probe is in contact with a flawed aluminum alloy plate;

FIG. 6A shows a flux-focusing eddy current probe's signal level response for a 2 KHz, 10.0 V p-p excitation coil signal when the probe is in contact with a 2 mm unflawed aluminum alloy plate;

FIG. 6B shows a flux-focusing eddy current probe's signal level response for a 2 KHz, 10.0 V p-p excitation coil signal when the probe is in contact with a 1 mm unflawed aluminum alloy plate;

FIG. 6C shows a flux-focusing eddy current probe's signal level response for a 2 KHz, 10.0 V p-p excitation coil signal when the probe is in free space;

FIG. 6D shows a flux-focusing eddy current probe's signal level response to thickness variations in aluminum as a function of frequency;

FIG. 7 shows another version of the flux-focusing eddy current probe embodying features of the present invention which provides additional resistance to edge effects and other conductive material discontinuities.

FIG. 8A shows another version of the flux-focusing eddy current probe embodying features of the present invention which provides additional resistance to lift-off response indicating conductive material fault;

FIG. 8B shows another version of the flux-focusing eddy current probe embodying features of the present invention which provides additional resistance to lift-off response indicating conductive material fault; and

FIG. 9 shows the eddy current probe system for locating crack tips.

DETAILED DESCRIPTION

With reference now to FIG. 1, wherein like numbers designate like components throughout all the several figures, the flux-focusing eddy current probe of the invention is particularly well adapted for non-destructive evaluation, and for fatigue testing of electrically conductive material. The flux-focusing eddy current probe generally designated at 10 includes an excitation coil, a flux focusing lens, and a pick-up coil. The probe 10 applies the eddy current principle to evaluate electrically conductive material 16 for faults. An alternating current supplied by a current source 15 electrically connected to the excitation coil 11 produces eddy

currents within conductive material **16** placed in proximity with the probe **10**. Magnetic fields created in the pick-up coil **13** are registered by an A.C. voltmeter **14** electrically connected to the pick-up coil **13**. The flux focusing lens **12** magnetically separates the excitation coil **11** from the pick-up coil **13** and produces high flux density at the edge of the pick-up coil **13**.

With reference now to FIG. 2, the excitation coil **11**, the flux focusing lens **12**, and the pick-up coil **13** are circular and concentrically arranged with the excitation coil **11** at the exterior of the probe **10**, the pick-up coil **13** at the innermost position of the probe **10**, and the flux focusing lens **12** between the coils **11** and **13**. The overall size of the probe **10** is primarily determined by the diameter of the flux focusing lens **12** which is a function of fault depth and fault isolation accuracy. The diameter of the lens **12** is minimized to reduce the overall size of the probe **10** and to provide accurate location information of identified faults, though it must be of sufficient size to support test frequencies of the applied current from the current source **15** and to maximize search area covered by the probe. Likewise, the thickness of the flux focusing lens is minimized to ensure energy created by the magnetic field of the excitation coil **11** produces energy in the pick-up coil **13** when the probe **10** is in free space or a flaw in the conductive material **16** crosses the boundary established by the lens **12**, though the lens **12** must provide isolation from direct magnetic energy of the excitation coil **11** from producing an alternating current in the pick-up coil **13** when the probe **10** is in contact with unflawed conductive material **16**. Direct energy transfer is avoided when the lens thickness is several times the skin depth of the magnetic flux within the lens. The size of the pick-up coil **13** is simply maximized to achieve the largest possible surface area for greatest signal sensitivity within the constraints dictated by the excitation coil **11** and the flux focusing lens **12**. It must be noted, however, that the smallest detectable flaw is approximately equal in size to one-half the inner diameter of the flux-focusing lens **12**.

With reference now to FIGS. 3, 4 and 5, an alternating current applied to the excitation coil **11** creates a magnetic field **41** which in turn creates eddy currents within conductive material **16**, FIG. 4A. The depth of penetration of the magnetic field **41** into the test material **16** is dependent upon the conductivity of the material **16** and the frequency of the applied current source. Consequently, the frequency of the drive signal is predetermined by the type of inspection being performed. Inspection for surface breaking flaws requires high frequency so as to concentrate the eddy currents at the surface of the material, whereas inspection for interior or back surface flaws requires low frequency such that the skin depth of the induced currents penetrate to the desired depth.

The magnetic field **41** is also established in the flux focusing lens **12**. The lens **12** is formed of conducting material high in magnetic permeability which provides a low reluctance path to divert the magnetic field away from the pick-up coil **13**. Examples of appropriate lens material include **1020** steel and mumetals. The point of maximum penetration of the concentrated magnetic field **41** within the lens **12** is at one half the height of the excitation coil **11**, FIG. 4A. In the preferred embodiment, the top of the pick-up coil **13** falls below this maximum penetration point.

In the absence of a conducting material test sample **16**, some leakage of the magnetic flux **31** around the lens **12** results, FIG. 3A. The leakage flux **32** produces a current in the pick-up coil **13** which provides a signal, FIG. 5B, to the A.C. voltmeter. When the probe is placed above a non-flawed electrically conductive surface, however, a complete

electromagnetic separation of the pick-up coil **13** from the excitation coil **11** can be achieved, FIG. 3B. The flux **33** is concentrated within the conductive material **16** and generates eddy currents **42**, FIG. 4B. The induced eddy currents **42** work to stop any change in the magnetic state of the system so that the leakage field within the interior of the flux focusing lens **12** is canceled, resulting in a null signal, FIG. 5A, to the A.C. voltmeter.

In the presence of a conductive material fault **43** which divides the area covered by the probe **10**, a change in eddy current flow results, FIG. 4C. The field produced by the eddy currents **44** and **45** pass through the area of the pick-up coil resulting in an alternating current being established in the pick-up coil **13**. The presence of a current in the pick-up coil **13** provides an unambiguous voltage signal as indicative of the presence of a conductive material fault. Where the tip of a fault **46** falls within the area covered by the pick-up coil **13**, FIG. 4D, the field produced by eddy current flow **47** is additive to the field of the excitation coil **11** and is greater than that produced by in air leakage flux **32** resulting in a higher voltage signal level, FIG. 5C, thus providing a maximum signal level.

With reference now to FIG. 6D, operation of the flux-focusing eddy current probe at reduced frequencies increases the penetration of the magnetic field and supports evaluation of conductive material thickness variations. As material thins, eddy currents in the conducting material are directed to within the area covered by the pick-up coil producing a voltage increase in the coil. Consequently, decreased material thickness produces increased flux-focusing eddy current probe output levels. The output level is directly related to the thickness of a specific material allowing measurement of the material's actual thickness.

With reference now to FIG. 7, an alternate probe configuration supports detecting faults close to an edge of the conductive material under test or near other conductive material discontinuities. An exterior shield **70** made of conductive material high in magnetic permeability focuses magnetic flux around the outside edge of the probe to prevent eddy currents from reflecting off a nearby conductive material edge and into the area of the pick-up coil. This allows the flux-focusing eddy current probe to be used near conductive material edges, however, the exterior shield **70** reduces the probe's overall sensitivity performance.

With reference now to FIG. 8, though the preferred embodiment is resistant to lift-off problems, alternate probe configurations are possible which provide further protection from lift-off conditions incorrectly indicating the presence of a conductive material fault. In the alternate embodiments, signals from a plurality of probes **10** combined within a casing **81**, FIG. 8A, or a plurality of pick-up coils **83A** and **83B** within a single excitation coil **11** and flux focusing lens **12**, FIG. 8B, are compared to one another. Equal, non-zero signal levels signify probe lift-off from the test material. Pick-up coils **13** or **83A** and **83B** are electrically connected to a differential amplifier **82**. Lift-off conditions result in equal signal level outputs such that the difference is zero and no fault indication is provided by the A.C. voltmeter **14**.

With reference now to FIG. 9, the eddy current probe system for fatigue evaluation of conductive material incorporates the flux-focusing eddy current probe **10** as a means of tracking fatigue crack growth in a conductive material **16** installed in a load frame **91**. The unambiguous flaw signal of the eddy current probe supports automated computer searching and identifying fatigue cracks. The probe **10** is used to scan conductive material **16** installed in the load frame **81**.

A computer 92 controls the probe's location over the conductive material by means of x-axis 93 and y-axis 94 motor drives which power their respective stepping motors 95 and 96. Additionally, the computer 92 continuously monitors the output of the probe 10 as it is scanned about the stress riser 16B in the sample and directs the load frame controller 97 as it cyclically fatigues the conductive material sample.

The area of the probe scan is initiated around a notch 16A in the conductive material sample. This location gives rise to high stress concentrations as the sample undergoes fatigue. Upon detection of crack growth, a large output signal from the probe 10 is received by the computer 92. The computer adjusts the position of the probe such that it is centered about the region of crack initiation. As the crack continues to grow, the computer updates the probe's position to trace the fatigue crack tip throughout the fatigue process. The position of the crack tip is determined by the peak output level of the probe as the crack path is traversed. The peak search routine using an algorithm similar to the grid-search chi-square minimization scheme increments the probe's location in the direction of the crack growth as determined by previous crack tip locations. The scan is continued until the new crack tip is found. Upon locating the crack tip, the probe is moved a short distance back along the path of the crack and the search is repeated. By continuously reevaluating the path of the crack near the crack tip, errors in crack tip location due to signal noise and crack branching are avoided. As the crack grows to predetermined lengths, experimental parameters such as the load level applied to the conductive material sample are adjusted by the computer. This method allows for completely automated experimental control of fatigue studies which saves time, allows continuous unattended testing, and archives fatigue growth rates and trajectories.

Although our invention has been illustrated and described with reference to the preferred embodiment thereof, we wish to have it understood that it is in no way limited to the details of such embodiment, but is capable of numerous modifications for many mechanisms, and is capable of numerous modifications within the scope of the appended claims.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A flux-focusing eddy current probe for non-destructive evaluation of an electrically conductive material comprising:

- (a) an excitation coil for inducing eddy currents within the electrically conductive material, the excitation coil having windings wherein the excitation coil's longitudinal axis is perpendicular to the surface of the electrically conductive material;
- (b) a pick-up coil having an outer edge and having windings which are surrounded by the windings of the excitation coil; and
- (c) a tubular flux focusing lens disposed between the excitation coil and the pick-up coil, composed of a conductive material having a high magnetic permeability, having a first opening opposite the surface of the electrically conductive material and having a second opening adjacent to the surface of the electrically conductive material and which prevents magnetic coupling between the excitation coil and the pick-up coil when said probe is placed above an unflawed electrically conductive material and which produces high flux density at the outer edge of the pick-up coil.

2. The flux-focusing eddy current probe as recited in claim 1, wherein the windings of the excitation and pick-up coils are substantially circular.

3. The flux-focusing eddy current probe as recited in claim 2, wherein the excitation coil is substantially concentrically disposed around the pick-up coil.

4. A flux-focusing eddy current probe as recited in claim 1, additionally comprising means for applying a current to the windings of the excitation coil, the current having a frequency range whose high frequency detects flaws on the surface of conducting material and whose low frequency detects flaws occurring within the conducting material and thickness variations of the conducting material.

5. The flux-focusing eddy current probe as recited in claim 4, wherein the high frequency is a frequency at which an opposing secondary magnetic field created by the eddy currents within the electrically conductive material overcomes a magnetic field produced by the excitation coil, and the lowest frequency is greater than a frequency at which the magnetic field produced by the excitation coil is directly detected by the pick-up coil when in contact with non-flawed electrically conductive material.

6. A flux-focusing eddy current probe as recited in claim 1, wherein the flux focusing lens has a substantially circular top composed of a conducting material of high magnetic permeability attached to the first opening of the flux focusing lens and which top encloses and magnetically isolates the first opening.

7. A flux-focusing eddy current probe as recited in claim 4, wherein the thickness of the flux focusing lens is greater than three skin depths of a magnetic flux generated by the current applied to the excitation coil.

8. The flux-focusing eddy current probe as recited in claim 3, wherein the flux focusing lens is substantially cylindrical and the excitation coil is concentrically disposed around the flux focusing lens.

9. The flux-focusing eddy current probe as recited in claim 8, wherein the height of the excitation coil is substantially equal to the height of the flux focusing lens.

10. The flux-focusing eddy current probe as recited in claim 9, wherein the height of the pick-up coil is less than one half the height of the excitation coil.

11. The flux-focusing eddy current probe as recited in claim 10, wherein the bottom edge of the pick-up coil is co-planar with the bottom edge of the excitation coil and the second opening of the flux focusing lens.

12. The flux-focusing eddy current probe as recited in claim 11, wherein the diameter of the flux focusing lens is no more than two times the size of a minimally detectable conductive material flaw.

13. An eddy current probe system for fatigue evaluation of electrically conductive material comprising a flux-focusing eddy current probe as recited in claim 1 that provides an output signal dependant upon a fault detected within the conducting material, additionally comprising;

- (a) a signal interpretation means to interpret and record the output signal of the eddy current probe;
- (b) a position recording means to record the x-axis and y-axis position of the probe over the electrically conductive material;
- (c) a controlling means to provide automated system control;
- (d) a positioning means for x-axis and y-axis positioning of the eddy current probe over the surface of the electrically conductive material; and
- (e) an automated loading means for applying tension and compression loads to opposite ends of the electrically conductive material causing the electrically conductive material to experience a fatigue crack having a tip.

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14. A flux-focusing eddy current probe system as recited in claim 13, wherein the controlling means controls the positioning means based on the output signal of the eddy current probe.

15. A flux-focusing eddy current probe system as recited in claim 13, wherein the controlling means controls the automated loading means based on the output signal of the eddy current probe.

16. A flux-focusing eddy current probe resistant to conductive material edge effects for non-destructive evaluation of an electrically conductive material comprising:

- (a) an excitation coil for inducing eddy currents within a conducting material, the excitation coil having windings wherein the excitation coil's longitudinal axis is perpendicular to the conducting material;
- (b) a pick-up coil having an outer edge and having windings which are surrounded by the windings of the excitation coil;
- (c) a tubular flux focusing lens disposed between the excitation coil and the pick-up coil, composed of a conductive material having a high magnetic permeability, having an opening at opposite ends of its longitudinal axis and which prevents magnetic coupling between the excitation coil and the pick-up coil when said probe is placed above an unflawed electrically

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conductive material and which produces high flux density at the outer edge of the pick-up coil; and

(d) a flux focusing shield which surrounds the excitation coil.

17. A flux-focusing eddy current probe highly resistant to lift off conditions for non-destructive evaluation of electrically conductive material comprising:

- (a) an excitation coil for inducing eddy currents within a conducting material, the excitation coil having windings wherein the excitation coil's longitudinal axis is perpendicular to the conducting material;
- (b) a plurality of pick-up coils each having windings which are surrounded by the windings of the excitation coil; and
- (c) a tubular flux focusing lens disposed between the excitation coil and the plurality of pick-up coils, composed of a conductive material having a high magnetic permeability, having an opening at opposite ends of its longitudinal axis, which prevents magnetic coupling between the excitation coil and the pick-up coils when said probe is placed above an unflawed electrically conductive material and which produces high flux density.

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